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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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GUIDELINES FOR THE USE OF COLOR IN SUBACS A DISPLAYS

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Naval Medical Research and Development Command
Research Work Unit M0100.001-1019

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Released by:
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SUMMARY PAGE

PROBLEM

To formulate an initial set of guidelines specifying the number of colors and their use in coding information in SUBACS A CRT displays.

FINDINGS

Based on existing literature and knowledge of how information will be displayed in SUBACS, six colors (red, yellow, green, cyan, blue, and white) were selected. Specific recommendations were made for the use of these colors in a large, representative sample of CRT displays. It was also strongly suggested that dim white ambient lighting be employed in areas where color CRTs will be used.

APPLICATION

These guidelines are designed to aid the design engineer in applying color to SUBACS A CRT displays. They have been submitted in similar form for consideration as aprt of the SUBACS A Engineering Notebook.

ADMINISTRATIVE INFORMATION

This research was conducted as aprt of the Naval Medical Research and Development Command Work Unit M0100.001-1019, "Improvement of sonar performance through modification of sonar displays" and Naval Sea Systems Command Project No. B47-022. It was submittee for review on 18 Sep 1984, approved for publication on 16 Oct 1984, and designated as NSMRL Rep. No. 1032

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ABSTRACT

Preliminary guidelines for the implementation of color in Submarine Advanced Combat System (SUBACS) displays have been formulated based on the human factors literature and examples of color coding in existing displays. A set of six colors, including the two opponent color pairs, was chosen. This allows absolute identification of color with a minimum period of learning. The coding scheme conforms with the cultural convention of associating green or blue with normal operating conditions, yellow with a cautionary state, and red with threat or danger. It was recommended that blue not be used for alphanumerics to avoid the loss of acuity that often results. The use of dim white lighting with color CRTs was recommended and reasons supplied for its advantages over the other possibilities.

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1.0 INTRODUCTION

The proper application of color to the CRT displays of the Submarine Advanced Combat System A (SUBACS A) requires a general knowledge of how color has been applied to other displays used in similar applications. Combining these findings with knowledge of the specific displays employed in SUBACS can then result in an initial set of guidelines for an effective use of color. It is the purpose of this report to provide preliminary guidelines based on both the available experimental data and the current versions of SUBACS displays.

We should first point out that the simple addition of color offers no necessary advantages over monochrome displays. In fact, color can be detrimental if used incorrectly. Its benefit is achieved only by the appropriate application of specific colors to particualr displays and environments. Teichner et al. [1], summarizing the results of 14 experiments, concluded that color has no peculiarities that make it different from achromatic codes (brightness, position, size, etc.). It is merely another dimension along which to code information; whether or not it should be used depends on how it compares to the achromatic alternatives in any <u>specific</u> situation. Thus the use of color is best treated on a case-by-case basis. However, there are certain instances in which color is claimed to be <u>generally</u> advantageous, and others where it is disadvantageous. The lists of advantages and disadvantages of color coding in Tables I and II are useful in helping to identify those types of applications likely to benefit from color and those that are not. They were compiled from a variety of sources [1-10].

Tables I and II reveal that color coding can offer many advantages when used properly. Its most useful application is to visual search [3,11], although it is an effective way to organize information on various types of displays. Most of the disadvantages of color result from the following conditions: using too many colors (more than 6 or so), using color in an irrelevant manner, using color in the few situations where it may be a hindrance or unnatural (e.g. coding quantitative information), using color under highly chromatic light sources, and employing color defective operators.

2.0 COLOR SET

<u>The six colors recommended for use on SUBACS displays are red, yellow, green, cyan (blue-green), blue, and white.</u> Previous work has shown that no one size of color set is best for all possible CRT applications. The optimal number of colors in a display depends on the specific task. This color set was limited to six, because, in SUBACS, it is desired that different colors be used to categorize different types of information, although they will be used redundantly with other codes. The color of a piece of information will, along with the other codes, convey the meaning of that information. Therefore, it is advantageous if the operator can not only discriminate the colors when seen side-by-side,

TABLE I

ADVANTAGES OF COLOR CODING

Search/Identification

Superior for finding a particular item of random location on a display
Superior to size, brightness, shape coding on identification tasks
Helpful for counting members of a class and locating information

Attention/Recognition/Memory

Focuses attention
Effective for coding low probability or very important events
Useful for alerting operator to a change in status
Superior for process control and monitoring
Speed of recognition increased for contrasting colors
Increases retention of information

Information

Increases information content; provides additional dimension to display
Acts as a "chunking" unit to organize information, separate categories
Need only a small number in most applications

Learning

Natural association of certain colors with well known physical states
Speed, ease of learning & comprehension; requires little additional training

Vision

Awareness of color common to all color normals
Improvement of visual acuity from color contrast at low luminance contrasts
Enhances contrast

Coding

Superior for areal coding, as in maps
Beneficial as a redundant code

Preference/Aesthetic

Generally preferred as less monotonous, producing less eye strain and fatigue
Has known aesthetic properties

Display Design

Allows for reduced display brightness
Reduces display clutter
Practical to implement
Colors effective under wide range of broad-band ambient lighting conditions

TABLE II

DISADVANTAGES OF COLOR CODING

Search/Identification

Inferior to alphanumeric coding on identification tasks

Attention/Recognition/Memory

May be a distractor when irrelevant or partially redundant

Information

Can result in information overload with too many colors

Learning

Problems arise when using colors that contradict cultural conventions

Vision

Not as effective in visual periphery
Can discriminate limited number of hues absolutely, less under adverse conditions
Approximately 8-10% males, .4% females color defective
Anomalous color vision with very small patches of color

Coding

Limited number of categories that can be coded
Generally not suitable for coding quantitative information
Most advantageous relative only to size, brightness, and shape; no better, or poorer than other coding sets
Irrelevant color can interfere with achromatic attributes of information

Preference/Aesthetic

People do not agree on hues when other aspects of color (such as saturation) are not controlled

but identify each color when it is perceived alone. There is general agreement that, where this type of absolute identification of color is desired, only a handful of colors is feasible (Table III) [2,4,6,8,12-14]. The present choice of six is near the upper limit of recommended set sizes.

This color set of six can actually be considered a set of five plus one. Only red, yellow, green, cyan, and white will be used for alphanumerics. Blue will be limited to highlighting and framing data, and area filling; it will not be used for any information that the operator must read. As will be seen, a set of five colors is sufficient to categorize the major types of information presented on SUBACS displays. Being required to discriminate only five colors and learning the types of information they represent should pose no problem for the operator, whereas discriminating ten or twelve is difficult without a great deal of practice. Using a small number of colors to code data on an absolute basis also allows for consistency in the use of colors within and across displays; red can have a similar meaning in whatever context the operator perceives it. Finally, limiting the set to five colors/categories does not increase display clutter.

The particular colors of red, yellow, green, cyan, blue, and white are recommended for the following reasons. They are well spaced throughout the visible spectrum and so are easier to discriminate than a set of hues grouped in one or two spectral locations. Four of the colors make up the two opponent-color pairs (red-green and yellow-blue) around which the human color vision system is organized [15]. These pairs offer maximum color contrast. Red, yellow, green, cyan, and white are easy to resolve visually. Blue was intentionally avoided as a code for alphanumerics, because it impairs visual acuity. When the eye is focused for white light, the short-wavelength blue light is focused in front of the retina. Consequently, viewing strong blue characters can result in "induced myopia", a condition of temporary near-sightedness. The only solution is to increase symbol and letter size. It was decided that limiting blue to non-alphanumeric applications such as area coding, framing, and axes, was the easier solution.

It is important to note that in implementing these six colors, it may be desirable to use different relative intensities in order to further increase discriminability. Saturation should also be maximal. Preliminary specifications for these six colors are given in the chromaticity diagram in Fig. 1. The corners of the triangle in this diagram are the chromaticities of the red, green, and blue phosphors of a Matsushita Standard Phosphor color monitor. This particular monitor was chosen because it is representative of color CRTs in general and is part of a graphics system currently in use at the Display Research Facility of the Naval Underwater Systems Center (NUSC). When this type of phosphor information becomes available for the actual monitor to be used in SUBACS, some adjustments to these specifications may be required. Only chromaticities falling within this triangle are capable of being produced

TABLE III

RECOMMENDED NUMBER OF COLORS FOR CRT DISPLAYS

Number	Source
3-7 (3-4 for absolute identification) (6-7 for comparative discrimination)	Silverstein [4]
3-4 beneficial 4 detrimental	Kinney & Culhane [12]
4	Wigert [6]
5-8 depending on viewing conditions	Conover & Kraft [8]
3-4, using complementary colors	Bouman (1978) in Ferranti [13]
6-8, avoid strong colors	C.I.E. (1982) in Ferranti [13]
max. of 5 for absolute identification	DeMars [2]
6	Hausing (1976) in Santucci et al. [14]

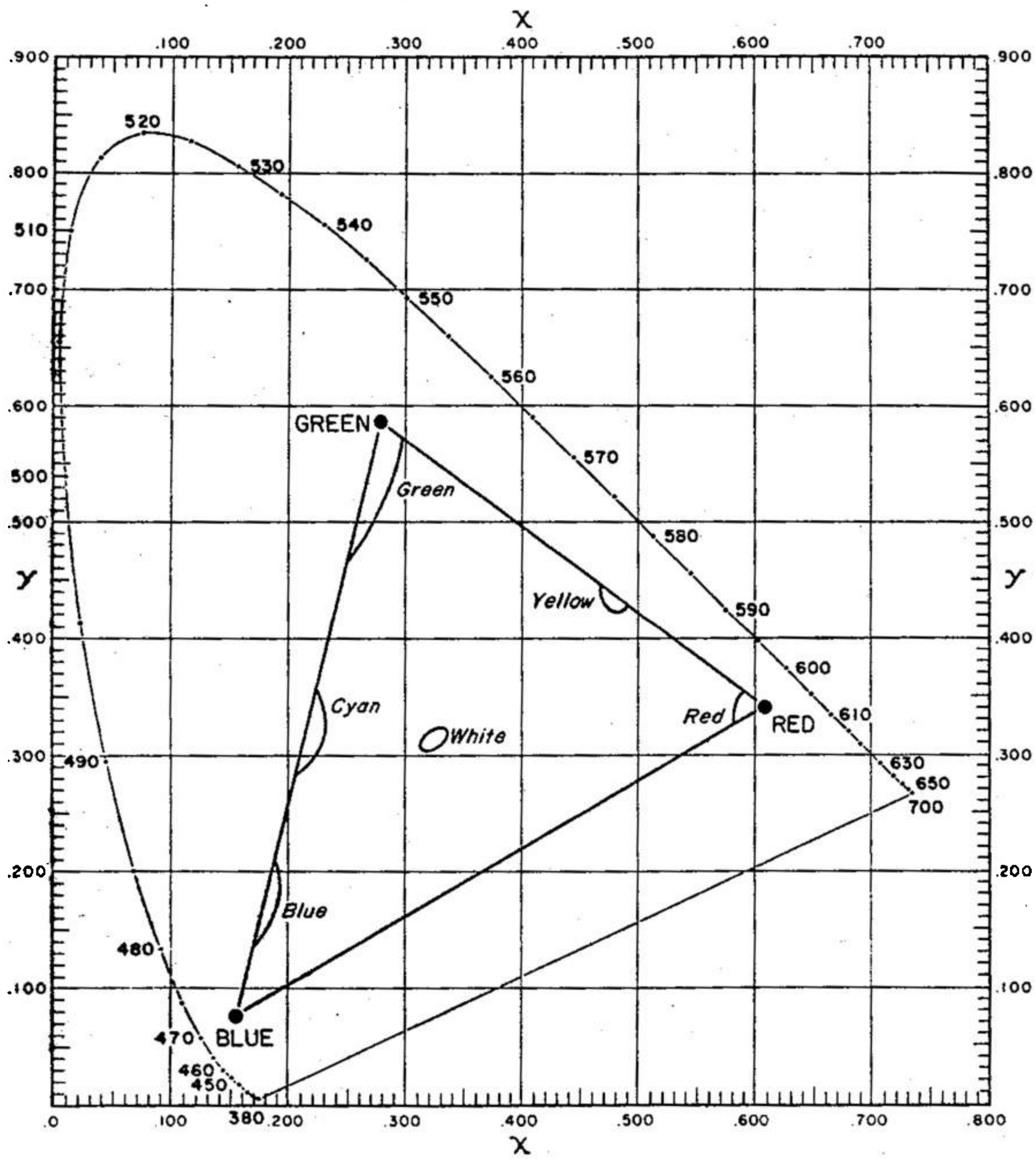

Figure 1. The chromaticities of the three phosphors of the Matsushita Standard Phosphor color monitor are the corners of the triangle on this C.I.E. chromaticity diagram. All colors that can be produced by this monitor fall within this triangle. The six labelled regions within the triangle represent the suggested chromaticities for the color set recommended for SUBACS A displays.

by this CRT. The suggested chromaticities for the six colors are shown as the labelled regions within the triangle. These regions are positioned at the edges of the phosphor triangle, providing for maximum possible saturation. Any color which falls within the boundaries of the six color regions should be acceptable. The regions are of unequal areas because equal distances in the diagram do not correspond to equal perceptual differences for the observer. For example, there can be a relatively large variation in the green region without much noticeable change in the visual perception of the color. Much less variation can occur in the yellow region without a noticeable shift in hue. Further fine-tuning of these specifications is part of a joint research program by NSMRL and NUSC.

Subsequent sections in this report detail the use of these six colors in specific SUBACS displays. However, a summary of the general principles for the use of color that are applicable to all CRT displays, drawn from the same sources listed in the Introduction, are presented in Table IV.

3.0 COLOR CODING

3.1 BACKGROUND COLOR

Since there was some evidence that a blue background might, under certain conditions, improve detection of colored targets [16], an experiment at NUSC in cooperation with NSMRL compared target detection on a simulated raw data sonar display, using various target colors on blue and the currently used black backgrounds. These results show that a blue background does not provide an improvement in target detection with any of the various raster colors tested [17]. The current background of black is therefore recommended.

3.2 INFORMATION TYPE

3.2.1 ALPHANUMERIC DATA

This section categorizes the types of alphanumeric information found in SUBACS A displays. This list does not include all alphanumeric data types found in the displays, but is, rather, a representative list of a large number of alphanumeric types. From this, a consistent philosophy of how color should be applied can be developed. The number of colors used for alphanumeric data was limited to the four primary display colors (red, yellow, green, cyan) plus white for own ship and cursor information. The use of blue is not recommended for alphanumeric data for the reasons discussed in section 2.0. A summary of how color was applied in each of these categories is provided in Table V.

3.2.1.1 OWN SHIP DATA

Own ship data includes information such as own ship speed,

TABLE IV

GENERAL PRINCIPLES FOR APPLYING COLOR TO CRT DISPLAYS

Keep Colors:

Task related
Relevant and conventional (e.g. red = "danger")
Consistent
To a minimum number
Discriminable and harmonious

When appropriate, color should be used to:

Designate particular object in a dense display
Demarcate a display area or visual event of special importance
Warn the operator of critical situation (most effective when there is a small number of alternatives)
Classify or group data where number of classifications are small, to reduce display clutter
Enhance pictorial realism when this is considered important
Code quantitative information on a map by using different saturations of the same hue
Code qualitative information on a map by using different hues

Remember:

All alphanumeric characters should be a minimum of 15' visual angle in size due to loss of resolution
Whenever possible evaluate experimentally the use of color in the specific application

TABLE V

ALPHANUMERIC DATA

CATEGORY COLOR	OWN SHIP DATA	CONTACT DATA	ENVIRON-MENTAL DATA	SYSTEM STATUS DATA	FUNCTIONAL CONFIGURATION PARAMETERS	SYSTEM ALERTS	CURSOR ALPHANUMERICS
RED		Hostile		Failure		Alarms	
YELLOW		Unknown		Degraded		Warnings	
GREEN			X	Normal		Notification	
CYAN		Friendly or Neutral			X		X
BLUE							
WHITE	X	Own Ship					X

course, depth, latitude, longitude, etc. It is recommended that this information be coded in white.

3.2.1.2 CONTACT DATA

The contact data field can include a great deal of information for several contacts simultaneously. These contacts can be categorized as (1) friendly and neutral, (2) unknown, or (3) hostile. The recommended coding scheme should help the operator to quickly determine the contact types being tracked. Friendly and neutral contact information would be coded in cyan, unknown or unclassified contacts in yellow, and hostile contacts or threats in red. This classification is consistent with the common "traffic light" coding scheme in which blue or green is a normal operating condition, yellow communicates a caution, and red requires immediate attention or action. In the case of defining tracker data types, this coding is partially redundant with the more specific shape coding employed in the assignment of the contact Naval Tactical Data System (NTDS) symbol. This conventional use of color will permit quick learning and understanding.

3.2.1.3 ENVIRONMENTAL DATA

Environmental data includes such information as sea state, wind speed, sound velocity, etc. This information is neutral in nature and it is recommended that it be coded in green.

3.2.1.4 SYSTEM STATUS DATA

Much of the system status data refers to the information found in the performance monitoring and fault localization (PM/FL) displays. Typically this function will be performed on a plasma panel device where color coding will not be available. For the information that will appear on color CRTs the following approach is recommended. The information being conveyed usually indicates how well the equipment is performing. To maintain a natural and consistent use of color coding, it is recommended that green indicate a normal operating state or a system functioning properly, yellow identify degraded states of operation, and red indicate failed systems and equipment.

3.2.1.5 FUNCTIONAL CONFIGURATION PARAMETERS

The functional configuration parameters refer to the alphanumerics that identify the current console station setup selections. These are the parameters which affect the performance of the system and are under the control of the console operator from a keypad, touch panel, or some other input device. It is recommended that these parameters be coded in a unique color to aid the operator in keeping the system setup parameters distinct from the other alphanumerics. Operator modifications can then be verified more quickly. The color recommended for these parameters is cyan. Default parameters or functional parameters not

under operator control should be green.

3.2.1.6 SYSTEM ALERTS

Three levels of alerts need to be addressed: (1) notifications, (2) warnings, and (3) alarms. Notifications provide information on changes in operating conditions or system operations; it is recommended that these alerts be coded in green. Warnings are serious conditions requiring the operator's attention as soon as possible without interrupting the current operation; it is recommended that they be coded in yellow. Alarms are the most serious of the alert messages and demand the operator's immediate attention; it is recommended that they be coded in red. This classification scheme preserves the relationship between color and meaning as applied above to contact data and system status data.

It should be noted that the use of flashing text is not recommended, as this may interfere with processing the message. A flashing cue can be effective, especially when the alert is in the visual periphery, but it would be better to flash a box around the message or symbol, rather than flashing the message. If it is absolutely necessary to flash the actual message then it should always be kept visible, alternating between a higher and lower intensity.

3.2.1.7 CURSOR ALPHANUMERICS

Cursor alphanumerics are the textual information (e.g. x-y coordinates) corresponding to the position of the cursor on the display. These data are referred to quite often, and it is desirable to have them stand out from the other alphanumerics. It is recommended that this information be coded in white or cyan, depending on the display and the surrounding colors.

3.2.2. RASTER GRAPHIC DATA

This section deals with display formats that are dense regions of minimally processed data in which the noise background is present and part of the raster representation. Characteristically these formats present data that are mapped to the pixel or cell, where a cell is a small pixel grouping. This information is quantitative in nature and employs the third coding dimension of amplitude (in addition to x-y positioning) in the presentation of the data. Amplitude is presently coded by using several intensities of a single color. In light of the lack of experimentation in this area (especially as applied to the SUBACS displays) it is recommended that the present format of several intensities be used until further investigation reveals whether or not color coding will improve performance. Using several intensities of a single color appears to be a natural way to differentiate quantitative data [10]. The use of color in raw data would be primarily an attempt to improve the operator's detection ability. There is, as yet, no evidence

#20 continued:

with color CRTs was recommended and reasons supplied for its advantages over the other possibilities.